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COMPLETE GUIDE TO SEMICONDUCTOR DEVICES

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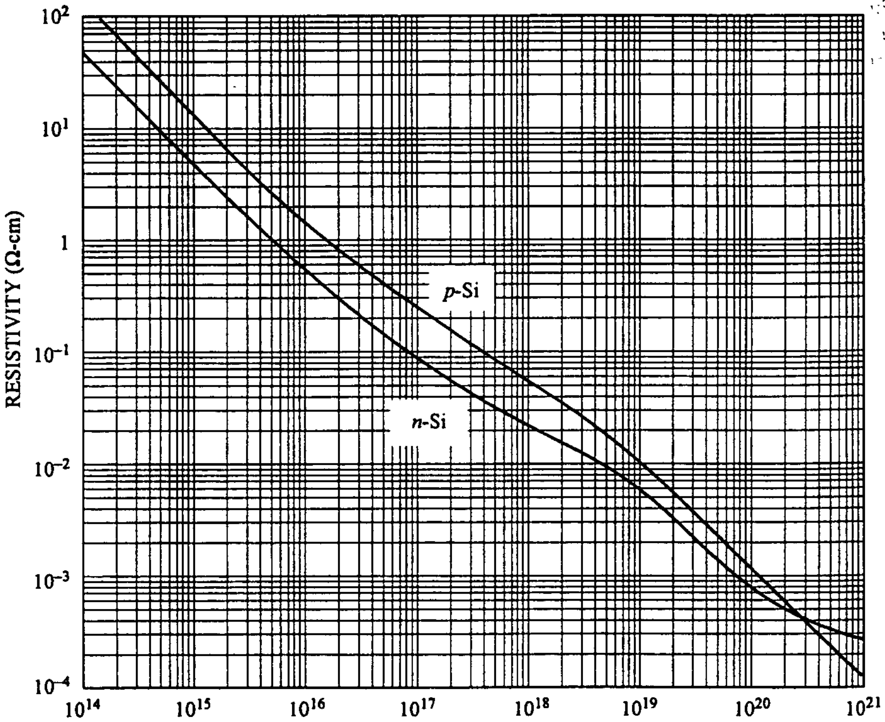
APPENDIX D4

RESISTIVITY AND MOBILITY



(a)

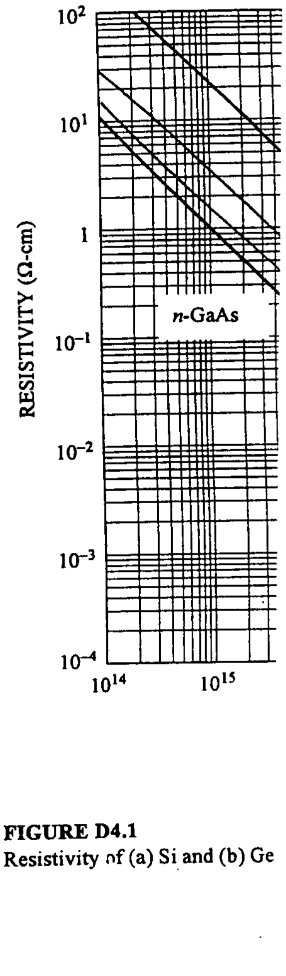


FIGURE D4.1
Resistivity of (a) Si and (b) Ge

APPENDIX D13

PROPERTIES OF METALS AND SILICIDES

TABLE D13.1
Properties of metals.[1]

Metals	Melting point (°C)	Resistivity ρ (20°C) ($\mu\Omega$-cm)	Thermal coef. of ρ (ppm/K)	Density (20°C) (g/cm^3)	Specific heat (J/kg-K)	Thermal conductivity (W/m-K)	Coef. of expan. (μ/K)
Aluminum	660.1	2.67	4500	2.70	917	238	23.5
Antimony	630.5	40.1	5100	6.68	209	23.8	8–11
Barium	729	60 (0°C)		3.5	285		18
Beryllium	1287	3.3	9000	1.848	2052	194	12
Bismuth	271	117	4600	9.80	124.8	9	13.4
Cadmium	320.9	7.3	4300	8.64	233.2	103	31
Calcium	839	3.7	4570	1.54	624	125	22
Cerium	798	85.4	8700	6.75	188	11.9	8
Cesium	28.5	20	4800	1.87	234	36.1	97
Chromium	1860	13.2	2140	7.1	461	91.3	6.5
Cobalt	1492	6.34	6600	8.9	427	96	12.5
Copper	1083.4	1.694	4300	8.96	386.0	397	17.0
Gallium	29.7			5.91	377	41.0	18.3
Germanium	937			5.32	310	56.4	5.75
Gold	1063	2.20	4000	19.3	130	315.5	14.1
Hafnium	2227	32.2	4400	13.1	147	22.9	6.0
Indium	156.4	8.8	5200	7.3	243	80.0	24.8
Iridium	2454	5.1	4500	22.4	130.6	146.5	6.8
Iron	1536	10.1	6500	7.87	456	78.2	12.1
Lead	327.4	20.6	4200	11.68	129.8	34.9	29.0
Lithium	181	9.29	4350	0.534	3517	76.1	56
Magnesium	649	4.2	4250	1.74	1038	155.5	26.0
Manganese	1244	144		7.4	486	7.8	23
Mercury	−38.87	95.9	1000	13.5	138	8.65	61
Molybdenum	2615	5.7	4350	10.2	251	137	5.1
Nickel	1455	6.9	6800	8.9	452	88.5	13.3
Niobium	2467	16.0	2600	8.6	268	54.1	7.2
Osmium	3030	8.8	4100	22.5	130	87.5	4.57
Palladium	1552	10.8	4200	12.0	247	75.5	11.0
Platinum	1769	10.58	3920	21.45	134.4	71.5	9.0

TABLE D13.1 (Continued)

Metals	Melting point (°C)
Potassium	63.2
Radium	700
Rhenium	3180
Rhodium	1966
Rubidium	38.8
Ruthenium	2310
Silicon	1412
Silver	960.8
Sodium	97.8
Strontium	770
Tantalum	2980
Tellurium	450
Thallium	304
Thorium	1755
Tin	231.9
Titanium	1667
Tungsten	3400
Uranium	1132
Vanadium	1902
Zinc	419.5
Zirconium	1852

TABLE D13.2
Properties of silicides.

Silicides	Resistivity ($\mu\Omega$-cm)
$CoSi_2$	18–25
$MoSi_2$	80–250
$NiSi_2$	≈ 50
Pd_2Si	30–35
PtSi	28–35
$TaSi_2$	30–45
$TiSi_2$	14–18
WSi_2	30–70

REFERENCES

1. C. Belove, Ed., *Handbo* 1986.
2. S. P. Murarka, *Silicides*
3. G. Georgiou, private cor

TABLE D13.1 (Continued)

Metals	Melting point (°C)	Resistivity ρ (20°C) (μΩ-cm)	Thermal coef. of ρ (ppm/K)	Density (20°C) (g/cm^3)	Specific heat (J/kg-K)	Thermal conductivity (W/m-K)	Coef. of expan. (μ/K)
Potassium	63.2	6.8	5700	0.86	754	104	83
Radium	700			5			
Rhenium	3180	18.7	4500	21.0	138	47.6	6.6
Rhodium	1966	4.7	4400	12.4	243	149	8.5
Rubidium	38.8	12.1	4800	1.53	356	58.3	9.0
Ruthenium	2310	7.7	4100	12.2	234	116.3	9.6
Silicon	1412			2.34	729	138.5	7.6
Silver	960.8	1.63	4100	10.5	234	425	19.1
Sodium	97.8	4.7	5500	0.97	1227	128	71
Strontium	770	23 (0°C)		2.6	737		100
Tantalum	2980	13.5	3500	16.6	142	57.55	6.5
Tellurium	450			6.24	134	3.8	
Thallium	304	16.6	5200	11.85	130	45.5	30
Thorium	1755	14	4000	11.5	100	49.2	11.2
Tin	231.9	12.6	4600	7.3	226	73.2	23.5
Titanium	1667	54	3800	4.5	528	21.6	8.9
Tungsten	3400	5.4	4800	19.3	138	174	4.5
Uranium	1132	27	3400	19	117	28	
Vanadium	1902	19.6	3900	6.1	498	31.6	8.3
Zinc	419.5	5.96	4200	7.14	394	119.5	31
Zirconium	1852	44	4400	6.49	289	22.6	5.9

TABLE D13.2

Properties of silicides.[2,3]

Silicides	Resistivity (μΩ-cm)	Formation temp. (°C)	Å of Si per Å of metal	Å of silicide per Å of metal
$CoSi_2$	18–25	> 550	3.64	3.52
$MoSi_2$	80–250	> 600	2.56	2.59
$NiSi_2$	≈ 50	750	3.65	3.63
Pd_2Si	30–35	> 400	0.68	≈ 1.69
PtSi	28–35	600–800	1.32	1.97
$TaSi_2$	30–45	> 600	2.21	2.40
$TiSi_2$	14–18	> 700	2.27	2.51
WSi_2	30–70	> 600	2.53	2.58

REFERENCES

1. C. Belove, Ed., *Handbook of modern electronics and electrical engineering*, Wiley, New York, 1986.
2. S. P. Murarka, *Silicides for VLSI applications*, Academic Press, New York, 1983.
3. G. Georgiou, private communications.

SEMICONDUCTOR INTEGRATED CIRCUIT PROCESSING TECHNOLOGY

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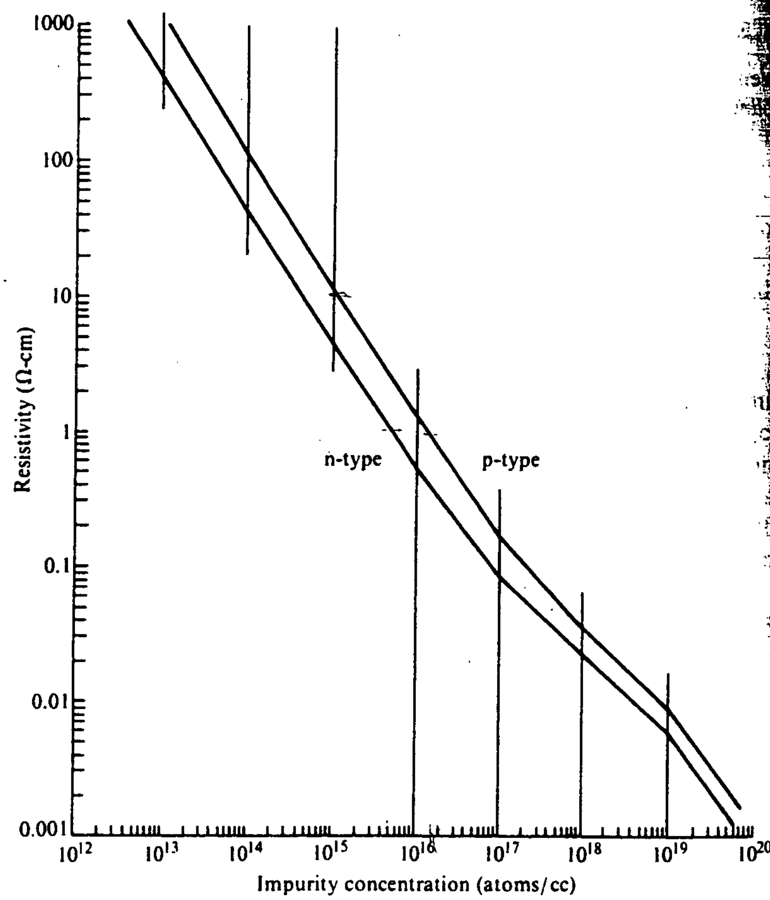
FIGURE 8.34

Resistivity versus impurity concentration for silicon. From data in S.M. Sze and J.C. Irving, *Solid State Electronics 11*, p. 599, 1968; W.R. Thurber et al., *J. Electrochem. Soc. 127*, p. 1807, 1980; and L.C. Linares and S.S. Li, *J. Electrochem. Soc. 128*. p. 601, 1981.



8.5.3 Determination of N_0

When the N_{ne} of Eq. 8.76 is known—for example,

$$N_{ne} \cong N_{\text{net}} = \left|N_0 \operatorname{erfc}\left(\frac{x}{2\sqrt{Dt}}\right) - N_B\right| \qquad 8.79$$

the sheet resistance can be calculated as a function of N_0 and N_B by using Eqs. 8.76 and 8.79, providing the mobility as a function of N_{ne} is known (see, for example, references 1 and 2 in Table 8.3 for data). By having made such calculations, curves such as those shown in Fig. 8.35 can be plotted for the range of values of interest and then N_0 read from them (79, 80). References 79 and 80 both have a selection of curves for error and Gaussian function distributions in silicon. However, reference 79 has used more recent electrical data. The Hall constant of the diffused layer can be measured, and, by using an analogous set of curves, the surface concentration can

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MICROELECTRONIC DEVICES

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The resistance of the bar is defined by

$$R \equiv \rho \frac{L}{A} \equiv \frac{V}{I_n} \tag{2-9}$$

where ρ is the *resistivity*. Substituting Eq. (2-8) into Eq. (2-9) and solving for ρ, we obtain

$$\frac{1}{\rho} = \sigma = q\mu_n n \tag{2-10}$$

where σ is the *conductivity*. By analogy, the hole drift current can be written as

$$I_p = qAp\mu_p\mathscr{E} \tag{2-11}$$

The overall resistivity of a semiconductor including the effects of electrons and holes becomes

$$\frac{1}{\rho} = q\mu_n n + q\mu_p p \tag{2-12}$$

The resistivity of a semiconductor is an important parameter in device design. Figure 2-8 shows the relationship between the impurity concentration and resistivity for both n- and p-type silicon and GaAs at room temperature. The deviation from linearity in these curves is caused by the nonlinear mobility effect.

2-3 CARRIER DIFFUSION

Diffusion is a phenomenon that occurs frequently in our daily experience, for example, the propagation of flower fragrance or the tinting of a cup of hot water

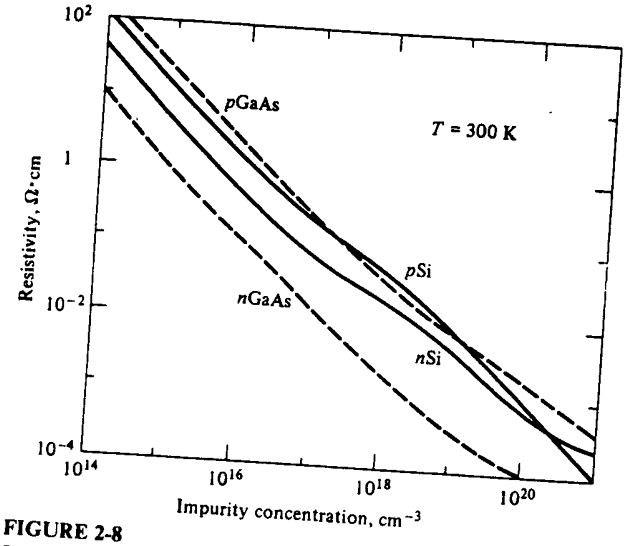

FIGURE 2-8
Resistivity vs. impurity concentration in Si and GaAs at 300 K. (*After Sze [1].*)